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Abstract

ON THE TRANSIENT HEAT TRANSFER FROM HOLLOW CYLINDRICAL FUEL ELEMENTS IN BOILING SUPERHEATED CONDITIONS

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The heat flux from a hollow cylindrical fuel cell can be obtained by applying the transient Fourier differential equation of heat conduction, neglecting the axial heat flow and assuming only slow pressure variations i.e. operation where the saturation temperature is nearly constant.

The cell configuration considered has the fissionable material in the form of a cylindrical annulus covered inside and outside by a metallic cladding. Cooling is accomplished by the flow of boiling water over the outside of the element and by the passage of superheated steam through the inner cylinder.

For the solution of the Fourier equation, the Laplace-transform of the relative change of the heat flux through the fuel element surface and the relative change of the power, will be used.

To determine the temperature of the contacting surfaces between cladding and fuel layers, as well as cladding and cooling medium it is necessary to know the transient temperature distribution in the cladding layers $\theta_1(t,r)$ and $\theta_3(t,r)$, and in the fuel region $\theta_2(t,r)$. These temperatures, are the solutions of the following differential equations with the boundary conditions as indicated for each region:

a) Outer shell $(r_1 \leq r \leq r_2)$

$$\frac{\partial \theta_1}{\partial t} = a_c^2 \Delta\theta_1$$

$$\text{where: } -\lambda_c \left(\frac{d\theta_1}{dr}\right)_{r=r_1} = \alpha_a(t)\left[(\theta_1)_{r=r_1} - \theta_a\right], \tag{1}$$

$$(\theta_1)_{r=r_2} = \theta_{12} \quad \text{and} \quad -\lambda_c \left(\frac{d\theta_1}{dr}\right)_{r=r_2} = -\lambda_B \left(\frac{d\theta_2}{dr}\right)_{r=r_2}$$

b) Fuel element $(r_2 \leq r \leq r_3)$

$$\frac{\partial \theta_2}{\partial t} = a_B^2 \Delta\theta_2 + \frac{W(t)}{\rho_B c_B} \text{ where } (\theta_2)_{r=r_2} = \theta_{12} \text{ and } (\theta_2)_{r=r_3} = \theta_{23} \tag{2}$$

c) Inner shell $(r_3 \leq r \leq r_i)$

$$\frac{\partial \theta_3}{\partial t} = a_c^2 \Delta\theta_3 \text{ where } \lambda_c \left(\frac{d\theta_3}{dr}\right)_{r=r_i} = \alpha_i(t)\left[(\theta_3)_{r=r_i} - \theta_i\right], \tag{3}$$

$$(\theta_3)_{r=r_3} = \theta_{23} \text{ and } \lambda_c \left(\frac{d\theta_3}{dr}\right)_{r=r_3} = \lambda_B \left(\frac{d\theta_2}{dr}\right)_{r=r_3}$$

where a_B^2, a_c^2 are the thermal diffusivities in fuel element and cladding respectively, λ_B, λ_c their thermal conductivities and ρ_B and c_B are the fuel element density and specific heat, respectively.

The power variation, W(t) is assumed to be small, thus, it can be expressed as:

$$W(t) = W_o(1+y(t)) \quad \text{where } y(t) \ll 1 \tag{4}$$

The numbers $\alpha_i(t)$ and $\alpha_a(t)$ represent the heat transfer coefficients from the inner and the outer shell to the cooling media, respectively.

When the Laplace transformation is applied to equations (1), (2) and (3), the following solutions are obtained in terms of the modified Bessel functions:

$$s\bar{\theta}_1(s,r) - \theta_1(o,r) = A_1 I_o(\Omega_1 r) + B_1 K_o(\Omega_1 r),$$

$$s\bar{\theta}_2(s,r) - \theta_2(o,r) = A_2 I_o(\Omega_2 r) + B_2 K_o(\Omega_2 r) + \frac{W_o}{\rho_B c_B}\bar{y}(s), \qquad (5)$$

$$s\bar{\theta}_3(s,r) - \theta_3(o,r) = A_3 I_o(\Omega_1 r) + B_3 K_o(\Omega_1 r),$$

where $\bar{\theta}(s,r)$ represents, in general, the Laplace transform function and $\theta(o,r)$ is the steady state solution, as given by Aoki. In addition, $\Omega_1 = \sqrt{s/a_c^2}$ and $\Omega_2 = \sqrt{s/a_c^2}$. The coefficients A_1, B_1, A_2, B_2 and A_3, B_3 are expressed as explicit functions of the known parameters.